Electromagnetic Simulation of Coupled Silicon and Diamond Microdisks and Slab Waveguides in the Mid-infrared

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Abstract— Electromagnetic numerical studies of silicon and diamond microdisks coupled with silicon and diamond slab waveguides are performed in the CO_2 laser emission region in the mid-infrared. Microdisk is the 2D analog of the microsphere and the slab waveguide is the 2D analog of the rectangular optical waveguide. The evanescent coupling between the waveguide and the microdisk results in efficient pumping of the whispering gallery modes of the microdisk. On-resonant and off-resonant studies are performed by tuning the laser wavelength to the microdisk whispering gallery modes.

1. INTRODUCTION

Photonic devices such as optical fibers, integrated photonic circuits, and lasers are great innovations, and played an important part in revolutionizing the modern world, because of their immunity to electromagnetic interference (EMI), low loss transmission at longer distances, and higher bandwidths [1]. Silicon photonics [2] is the current state-of-art, and photonics devices such as silicon Raman lasers have already been demonstrated in the near-infrared [3]. The concept of whispering gallery modes (WGMs) is not new, as it was first described by Lord Rayleigh in 1910 [4]. The WGMs rely greatly on the geometry of the resonator [5]. WGMs are favored due to their high quality factors [6], on the order of 10^6 [7] and 10^7 [8]. Here, we present electromagnetic numerical simulation results of microdisks coupled with optical waveguides, the on- and off-resonance conditions for silicon and diamond microdisks in air placed on silicon and diamond slab waveguides excited with tunable mid-infrared lasers operating at wavelengths of 9.2–10.7 micrometers. We demonstrate our approach by performing a simulation of the out of plane electric field strength of evanescently coupled silicon and diamond microdisks (the 2D analog of the microspheres) with silicon and diamond slab waveguides (the 2D analog of optical waveguides) [9]. We adopted MIT electromagnetic equation propagation (MEEP) tool based on finite difference time domain (FDTD) method to perform simulations [10].

2. PROPOSED EXPERIMENTAL SETUP

The overall proposed experimental setup is shown in Figure 1. A tunable CO_2 laser with wavelength range of 9.2–10.7 µm can be used to excite the WGMs in microdisks with radius $a = 15\,\mu\text{m}$ and refractive index $n = 3.41$ for silicon, and $n = 2.38$ for diamond, respectively. The input laser is coupled to a slab waveguide. The width of the slab waveguide is $w = 3\,\mu\text{m}$. There is a beam splitter (BS) placed in the path of transmitted light at 45° to reduce the intensity of light falling on the passive infrared (PIR) sensor 3. The transmission at 0° and scattering at 90° and 270° from the microsphere can be collected by PIR sensors, whose signals can be sent to a data acquisition (DAQ) box, which is connected to a computer through universal serial bus (USB) interface.

3. ELECTROMAGNETIC SIMULATION GEOMETRY

The FDTD electromagnetic numerical simulation geometry is shown in Figure 2. The microdisk resonator placed on the area near the evanescent field of the slab waveguide will enable light to couple from the waveguide to the microdisk resonator, at the WGMs of the microdisk resonator. In the simulations, the excitation port is at the left hand side of the slab waveguide. The incident light wave is oscillating in the z-direction (out of the plane) and the amplitude of the E_z component is calculated everywhere on the xy plane.

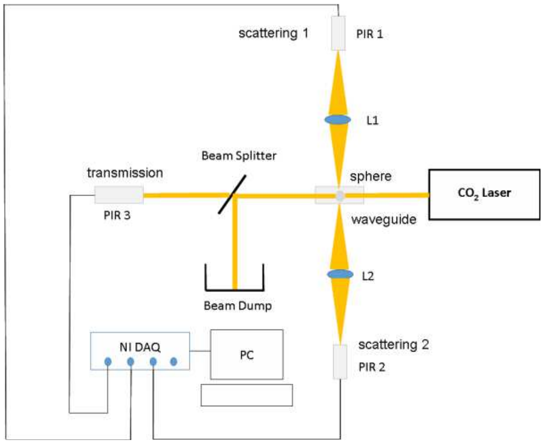


Figure 1: Proposed experimental setup for coupling of silicon microdisk to a slab waveguide.

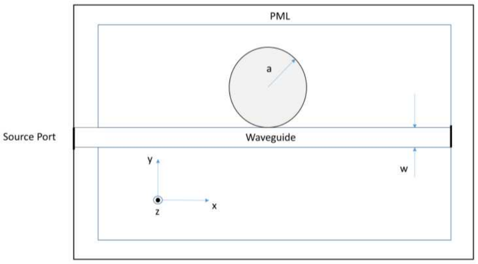
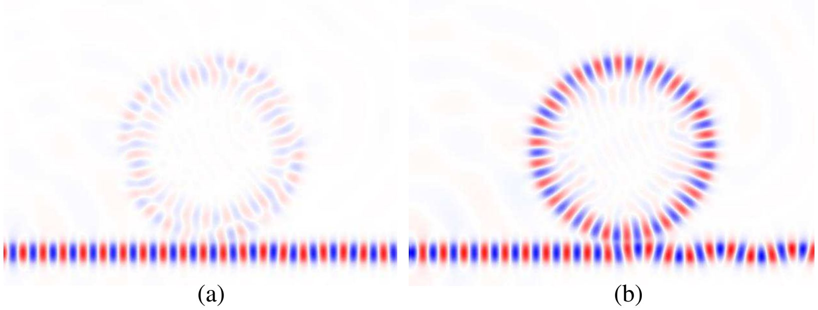


Figure 2: Geometry of the electromagnetic FDTD simulation.

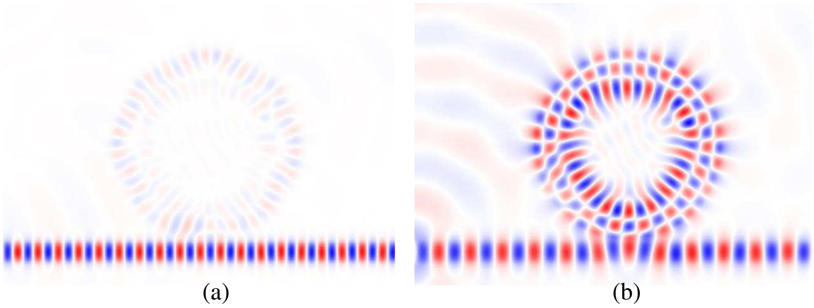
4. SIMULATION RESULTS AND DISCUSSION

Figure 3(a) shows the off-resonance, and 3(b) the on-resonance condition for silicon waveguide ($m = 3.41$) and silicon microdisk ($m = 3.41$) coupling. The off-resonance wavelength is 10.325 μm, while the on-resonance wavelength is 10.5 μm. For the on-resonance case, the angular mode number is $n = 26$ and radial mode order is $l = 1$. Figure 4(a) shows the off-resonance, and 4(b) the on-resonance condition for diamond waveguide ($m = 2.38$) and silicon microdisk ($m = 3.41$) coupling. The off-resonance wavelength is 10.2 μm, while the on-resonance wavelength is 10.62 μm. For the on-resonance case the angular mode number is $n = 18$ and radial mode order is $l = 3$. Figure 5(a) shows the off-resonance, and 5(b) the on-resonance condition for diamond waveguide ($m = 2.38$) and diamond microdisk ($m = 2.38$) coupling. The off-resonance wavelength is 10.30 μm, while the on-resonance wavelength is 10.62 μm. For the on-resonance case the angular mode number is $n = 17$ and radial mode order is $l = 1$. Figure 6 shows silicon waveguide ($m = 3.41$) and diamond microdisk ($m = 2.38$) coupling. The on-resonance amplitude in Figure 6 is negligible, because of the smaller refractive index of diamond microdisk as compared to the silicon waveguide.



(a) (b)

Figure 3: (a) The off-resonance and (b) on-resonance for a silicon microdisk on a silicon slab waveguide.



(a) (b)

Figure 4: (a) The off-resonance and (b) on-resonance for a silicon microdisk on a diamond slab waveguide.

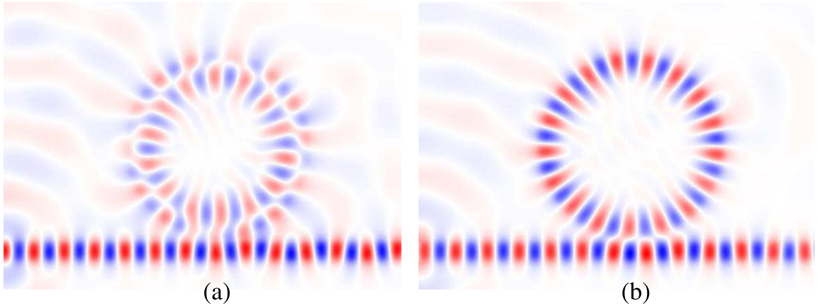


Figure 5: (a) The off-resonance and (b) on-resonance for a diamond microdisk on a diamond slab waveguide.

Figure 6: The case for a diamond microdisk on a silicon slab waveguide.

5. CONCLUSIONS

We numerically simulated the amplitude of the z component of the electric field in silicon and diamond waveguides coupled to silicon and diamond microdisks in the mid-infrared wavelength range of 9.2–10.7 μm of CO_2 lasers. The microdisk is the 2D analog of the microsphere and the slab waveguide is the 2D analog of the rectangular optical waveguide. The evanescent coupling between the waveguide and the microdisk results in efficient pumping of the whispering gallery modes of the microdisk. The on-resonant and off-resonant studies are performed by tuning the CO_2 laser wavelength to the microdisk whispering gallery mode. Silicon microsphere on silicon and diamond waveguides shows very strong resonances, whereas diamond microsphere resonances on diamond and silicon waveguides are not as strong.

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